Vascular Problem-Solving and Case Presentation:
Vessels of the Neck

John Huston, III, M.D.
Mayo Clinic College of Medicine
Rochester MN

Introduction

Vascular imaging techniques such as DSA, CT angiography and MR angiography allow diagnosis of important clinical conditions involving the vasculature of the neck. However, the evaluation of the carotid arteries for clinically significant atherosclerotic disease is by far the most frequent indication for imaging the neck vasculature. As a result, this presentation will include discussion of important vasculature conditions involving the neck and associated artifacts, but will focus on carotid atherosclerotic imaging.

MR Angiography Techniques

There has been remarkable development of MR angiography during the past decade. The development of carotid MR angiography reflects the dynamic evolution of MR imaging in general. The initial application was sagittal three-dimensional (3D) time of flight which was limited by flow saturation, especially for patients with high grade stenosis and distal slower flow. Axial two-dimensional (2D) time of flight demonstrated sensitivity to slow flow but because of intravoxel phase dispersion, poorly depicted the stenosis segment associated with carotid plaque. By serendipity, the presence of a signal void using 2D time of flight corresponded to a carotid stenosis of greater than 60%. The development of multiple overlapping thin slab acquisition 3D time of flight improved both the sensitivity to slow flow and the depiction of carotid stenosis. Limitations remained, including signal voids with high-grade stenoses and occasional underestimation of the degree of stenosis because of "ballooning" artifacts. The introduction of elliptical centric contrast-enhanced techniques transformed MR angiography from a flow-dependent technique analogous to ultrasound into a contrast luminal filling technique analogous to conventional angiography. With each development in carotid MR angiography, the improved accuracy was documented through patient studies that used conventional angiography as a reference standard. A recurrent theme in these investigations is that the specificity and accuracy of source images are superior to maximum intensity projection (MIP) images.

Elliptical Centric Contrast-Enhanced MR Angiography

Elliptical centric contrast-enhanced (CE) 3D MR angiography uses a novel k-space sampling technique. Initially the center of k-space is sampled where the large scale signal intensity or contrast information of the image is determined, then the views progressively more distant from the center are acquired until the periphery of k-space is reached, where the high detail of the image is determined. This process provides intrinsic venous suppression. As a result, scans with imaging times exceeding one minute can be performed to attain high spatial resolution and yet reliably provide adequate venous suppression. With the elliptical centric or other centric methods for carotid MR angiography, timing of the 3D sequence is vital because the initiation of the sequence must coincide with the peak of contrast bolus.

Integrated Carotid CE MR Angiographic Examination

Through experience and clinical trials an integrated carotid CE MR angiographic examination has been developed in our practice. The examination begins with a 2D phase contrast scout, which is followed by a 2D time of flight sequence and concludes with the elliptical centric CE MR angiogram. The coronal 2D phase contrast scout is used to identify the level of the petrous portion of the internal carotid arteries. The 2D time of flight is obtained so that the first section is just superior to the petrous portion of the internal carotid artery, with 100 axial 1.5 mm thick sections prescribed inferiorly. The 2D time of flight sequence first serves as a screen so that if vessels are normal or stenosis is minimal, no further imaging may be required. The gradient performance of selected lobes of the 2D time of flight sequence is de-rated to 10 mT/m and 17 T/m/s so it does not use the reduced TE capabilities of high speed gradients. Results of the 2D time of flight studies using this gradient performance demonstrate that a signal void typically occurs when a stenosis is 60% or greater. The 2D sequence also serves as a scout for the CE MR angiographic sequence. With the 2D time of flight sequence as a scout the FOV of the CE examination enables inclusion of the entire vertebral arteries from their origin to the basilar artery as well as most of the common carotid arteries and both internal carotid arteries from their origins to the proximal carotid siphon. The entire integrated examination typically can be performed in 20 minutes in addition to the time needed to insert the intravenous catheter. If the aortic arch or common carotid origins need to be visualized, a second elliptical centric CE sequence is performed centered on the superior aortic arch. Limited field of views are used to achieve the smallest voxel size that can currently be supported by signal to noise ratio at 1.5T. When measuring atherosclerotic segment of the internal carotid artery, higher spatial resolution allows more accurate determination of arterial stenosis. Developments are occurring to allow larger field of views with equal or better performance. These include the use of parallel imaging, improved coils, 3.0T and contrast agents with greater T1 shortening capabilities.

Pitfalls and Artifacts

CE MR angiography timing. When utilizing elliptical centric or other centric CE MR angiographic techniques, it is crucial to initiate scanning when the contrast bolus is at its maximum. The two commonly used techniques to ensure accurate timing include bolus test and fluoroscopic triggering. A typical test bolus uses 1-2 cc of contrast injected at the same rate planned for contrast injection during the 3D acquisition followed by the analogous of saline flush which is typically 25 – 30 cc. Dynamic scans are acquired with a typical temporal resolution of one image per second. Following the acquisition of the sequence, the appropriate arrival of contrast is retrospectively determined. This becomes the scan delay time for the 3D CE MR angiographic sequence. Fluoroscopic triggering may use either interactive graphic tools to facilitate the selection of a monitoring plane or a projection technique through the anticipated MR angiographic volume. The fluoroscopic sequence is initiated as the contrast is injected. When the arrival of the contrast is detected, the 3D CE MR angiographic sequence is initiated. Triggering the sequence prior to the peak arrival of contrast will result in poor opacification of the vessels with peripheral enhancement. Delayed initiation of the sequence will result in venous opacification.

Image Interpretation and Post-processing. Upon the acquisition of the 3D MR angiographic sequence, it is typical that an entire volume MIP image is processed automatically. A common practice is to make sub-volumes of the vessels of interest by creating at least at a minimum the right carotid and right vertebral separated from the left carotid and left vertebral circulations. Display of these images in multiple projections assists in identification of focus of greatest

stenosis. The wide use of MIPs as opposed to other techniques such as volume rendering and shaded surface display is related to the simplicity of the MIPs creation and use. However, limitations of the MIP technique have been detailed. The most significant shortcoming is the overestimation of stenotic lesions. Published studies have consistently demonstrated that the use of source images for lesion measurement offer both a more specific and more accurate measurement of stenosis.

Metal Artifact. Patients having previously undergone carotid endarterectomy surgery may have small vascular metalic clips within the surgical bed. Occasionally, this clinical history is unavailable prior to performing the MR angiogram. These metal clips can result in pseudostenosis, mimicking the presence of a significant atherosclerotic stenosis. It is especially useful to review the source images where the presence of the typical rings of high and low signal can alert one to the presence of these metallic foreign bodies.

"Feathering" Ringing Artifact. Occasionally, blurring or loss of signal can occur in small arteries of the neck, especially the vertebral arteries. This most commonly occurs in young patients with rapid circulation time. This ringing artifact which in our practice has termed "feathering" results from the rapidly changing signal in small vascular structures during the sampling of the center of k-space. Review of source images, especially axially reformatted images, will demonstrate a characteristic pattern of multiple rings or targets. These patterns of alternating high and low signal result in interference patterns that reinforces or cancels the signals within the vertebral arteries. The degree of distortion is increased as the number of opacified vessels increase and when the vertebral arteries are small in caliber. The vessels that cause this distortion are likely small muscular arteries. This feathering artifact can be decreased by initiating the scan earlier.

Carotid Atherosclerotic Disease

Ischemic stroke is the third leading cause of death in the United States with nearly 600,000 cases each year. Atherosclerotic disease resulting in stenosis of the carotid artery with associated thromboemboli accounts for a substantial percent of these cerebral infarctions. Findings of prospective randomized trials including the North American Symptomatic Carotid Endarterectomy Trial (NASCET), European Carotid Surgical Trial and Asymptomatic Carotid Surgical Trial (ACST) have shown a surgical benefit for selected symptomatic patients with stenosis as low as 50% and a for asymptomatic patients of 60% or greater. Conventional DSA has been traditionally the preoperative test to identify these high grade carotid stenotic lesions to determine whether surgical intervention including endarterectromy or stenting was necessary. Improving noninvasive methods of preoperative evaluation including ultrasound, MR angiography, CT angiography or a combination of these tests have replaced DSA in most practices. However, the burden for accurate depiction of carotid stenosis increases as the surgical intervention is based on these noninvasive techniques. Atherosclerosis affects the walls of large and medium-sized elastic and muscular arteries of the neck. It rarely involves smaller vessels. Recently, our understanding of the biology of atherosclerosis has changed. No longer are the arteries viewed as inert pipes accumulating fatty plaques. It is now understood that inflammation has a central role in the development and progression of atherosclerosis. Inflammation is central to the build up of fat and cholesterol containing plaques and can result in rupture of vulnerable plaques. Noninvasive techniques have difficulty identifying ulcerations which can have important clinical significance.

Fibromuscular Dysplasia (FMD)

Fibromuscular dysplasia is a segmental nonatherosclerotic change within the carotid artery whose etiology is not completely known. Thoughts are that FMD represents a developmental abnormality that primarily affects medium-sized muscular arteries. In a typical case, there is a smooth contour of a normal lumen replaced by irregular alternating segments of constriction and dilatation. The focal constriction is caused by an abundance of abnormal hyperplastic and fibrotic media, where as the pouch-like dilatations are due to the locally reduced or absent media. With imaging the appearance is typically referred to as a "string of beads" appearance.

Dissection

Dissection is an additional cause of ischemic stroke and transit ischemic attacks often presenting in a younger age group than atherosclerotic events. While dissections occur typically three times more frequently in the vertebral arteries, it is not uncommon to encounter this entity within the internal carotid arteries. A dissection may occur as an isolated event or extension of an aortic dissection. A history of trauma may or may not be present and if absent, the dissection is considered a spontaneous event. A dissection typically occurs in the outer media of the artery. Depending on the location, a false lumen may be created that is completely separate from the lumen resulting in a pseudoaneurysm that may have a "windsock" configuration. Dissections often resolve, frequently regress and rarely progress.

References

Bernstein MA, Huston J III, Lin C, Gibbs GF, Felmlee JP. High-resolution intracranial and cervical MRA at 3.0T: Technical considerations and initial experience. *Magnetic Resonance in Medicine* 2001; 46:955-962.

Hu HH, Madhuranthakam AJ, Kruger DG, Huston J III, Riederer SJ. Improved venous suppression and spatial resolution with SENSE in elliptical centric 3D contrast-enhanced MR angiography. *Magn Reson Med* 2004; 52(4):761-5.

Huston J III, Fain SB, Riederer SJ, Wilman AH, Bernstein MA, Busse RF. Carotid arteries: maximizing arterial to venous contrast in fluoroscopically triggered contrast-enhanced MR angiography with elliptic centric view ordering. *Radiology* 1999; 211:265-273.

Huston J III, Fain SB, Wald JT, Luetmer PH, Rydberg CH, Covarrubias DJ, Riederer SJ, Bernstein MA, Brown RD, Meyer FB, Bower TC, Schleck CD. Carotid artery: elliptical centric contrast-enhanced MR angiography compared with conventional angiography. *Radiology* 1993; 186:316-318.

Korosec FR, Frayne R, Grist TM, Mistretta CA. Time-resolved contrast-enhanced 3D MR angiography. *Magn Reson Med* 1996; 36:345-351.

Meyer JM, Buecker A, Spuentrup E, Schuermann K, Huetten M, Hilgers RD, van Vaals JJ, Guenther RW. Improved in-stent magnetic resonance angiography with high flip angle excitation. *Invest Radiol* 2001 Nov; 36(11):677-81.

Mistretta CA, Grist TM, Korosec FR, et al. 3D time-resolved contrast-enhanced MR DSA : advantages and tradeoffs. *Magn Reson Med* 1998; 40:571-581.

Mokri B, Houser OW, Sandok BA, Piepgras DG. Spontaneous dissections of the vertebral arteries. *Neurology* 1988; 38:880-885.

Mokri B. Spontaneous dissections of internal carotid arteries. *Neurologist* 1997; 3:104-119.
Patetosis P, Gable DR, Garrett WV. Management of carotid body paragangliomas and review of a 30 year experience. *Annals of Vascular Surgery* 2002; 16:331-338.

Prince MR, Grist TM, Debatin JF. 3D contrast MR angiography, 3rd ed. Berlin: Springer; 2003.

Prince MR, Narasimham DL, Stanley JC, et al. Breath-hold gadolinium-enhanced MR angiography of the abdominal aorta and its major branches. *Radiology* 1995; 197:785-792.

Riederer SJ, Bernstein MA, Breen JF, Busse RF, Ehman RL, Fain SB, Hulshizer TC, Huston J III, King BF, Kruger DG, Rossman PJ, Shah S. Three-dimensional contrast-enhanced MR angiography with real-time fluoroscopic triggering: design specifications and technical reliability in 330 patient studies. *Radiology* 2000 May; 215(2): 584-93.

Sahdev A, Sohaib A, Monson JP, Grossman AB, Chew SL, Reznek RH. CT and MR imaging of unusual locations of extra-adrenal paragangliomas (pheochromocytomas). *Journal of European Radiology* 2005; 15:85-92.

Saloner D. Determinants of image appearance in contrast-enhanced magnetic resonance angiography. A review. *Invest Radiol* 1998 Sept; 33(9):488-95. Review.

Schievink WI, Mokri B, Piepgras DG, Kuiper JD. Recurrent spontaneous arterial dissections: Risk of familial versus nonfamilial disease. *Stroke* 1996; 27:622-624.

Schoenberg SO, Bock M, Knopp MV, et al. Renal arteries: optimization of three-dimensional gadolinium-enhanced MR angiography with bolus timing-independent fast multiphase acquisition in a single breath hold. *Radiology* 1999; 211:667-679.

Weiger M, Pruessmann KP, Kassner A, Roditi G, Lawton T, Reid A, Boesiger P. Contrast-enhanced 3D MRA using SENSE. *J Magn Reson Imaging* 2000 Nov; 12(5): 671-7.

Wilman AH, Riederer SJ, Huston J III, Wald JT, Debbins JP. Arterial phase carotid and vertebral artery imaging in 3D contrast-enhanced MR angiography by combining fluoroscopic triggering with elliptical centric acquisition order. *Magn Reson Med* 1998; 40:24-35.

Wilman AH, Riederer SJ. Improved centric phase encoding orders for three dimensional magnetization prepared MR angiography. *Magn Reson Med* 1996; 36:384-392.

Wilman AH, Riederer SJ. Performance of an elliptical centric view order for signal enhancement and motion artifact suppression in breathhold three dimensional gradient echo imaging. *Magn Reson Med* 1997; 38:793-802.